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A STUDY OF THE LESSER MIGRATORY GRASSHOPPER[1]

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INTRODUCTION

A survey of the publications relating to grasshoppers has shown the need of a more detailed study of the life histories and habits of these insects. Most of the existing literature deals with the subjects of taxonomy and control. The matter on life history contained in it is in character general and pertains mostly to the group as a whole. This is probably due to the fact that all species of grasshoppers have many things in common relative to their development and habits. It is true, however, that enough differences exist to warrant the making of separate studies of each species. The material for this bulletin was obtained from observations made in the field and laboratory, supplemented by excerpts from the literature. The field observations recorded herein were made in Montana in the period extending from November, 1923, to November, 1927.

HISTORY AND SYNONYMY

Melanoplus atlanis, or the lesser migratory locust, as it is known in the literature, was first described by Saussure in 1861 (*25*)[2] as *Pezottetix mexicana* (male and female, temperate Mexico). It was

[1] *Melanoplus atlanis* (Riley) [=*Melanoplus mexicanus* (Saussure)]; order Orthoptera, family Acrididae, subfamily Cyrtacanthacrinae.

[2] Reference is made by italic numbers in parentheses to Literature Cited, p. 32.

described as *Caloptenus atlanis* by Riley in 1875 (*22, p. 169*) (male and female, New Hampshire). In 1897 Scudder (*27*) replaced Caloptenus of Burmeister with Melanoplus of Stål, basing his action on the fact that:

> The foundation for our present knowledge of the structural features of the *Melanopli* was laid by Stål (Recensio Orthopterorum I, 1873), and enlarged in his Systema Acrideodeorum (1878) and his Observations Orthoptérologiques III (1878).

In 1917 Hebard (*5, p. 271*) stated:

> Careful study of the literature and the extensive series at hand gives conclusive evidence that the widespread and abundant species, known universally as *M. atlanis*, must be called *mexicanus*, *atlanis* having been described in 1875. The name *atlanis* accordingly is alone retained for the race of *mexicanus* widely distributed throughout the eastern United States and vicinity. The species clearly divides into several geographic races. * * *

More recently Hebard (*6, p. 112*) has said:

> Detailed study is needed to determine the number and distribution of the races of *mexicanus*. Until then many of the numerous names which have been proposed can not be assigned to synonymy, or given racial status, with any degree of assurance. Another difficult problem is that of the migratory grasshopper, known as *M. spretus* (Walsh), which may prove to be only a migratory phase of this same insect.

Owing to the fact that the name *Melanoplus atlanis* is almost universally known, it is retained in this bulletin.

In 1873 Cyrus Thomas (*29, p. 165*) described *Caloptenus spretus*, but did not mention *atlanis*, and said of the former:

> I have traced this species from Texas northward to the north shore of Lake Winnipeg, in British America, and from the Mississippi River westward to the Sierra Nevada range. It does not appear to be found in California, and but a short distance southward in Arizona.

Melanoplus atlanis first came into prominence in Riley's work on the Rocky Mountain locust, *M. spretus*, in 1877 (*23, 24*). Previous to this *atlanis* had probably been confused with *spretus* and *femur-rubrum*, and in this work Riley compares the three species. He places *atlanis* as structurally nearer *spretus* than *femur-rubrum*, differing mainly in size and color, *atlanis* being much smaller and more distinctly marked than *spretus*. Riley also states that *spretus* can not live in the Atlantic States or east of the ninety-fourth meridian, and calls *atlanis* the Atlantic migratory locust. Furthermore, Riley attributes to *atlanis* about the same flying ability as to *spretus*, and states that the variety of the former occurring in the Mississippi Valley is larger than the typical or Atlantic form. Owing to the immense amount of interest aroused by the terrible ravages of the Rocky Mountain locust during the decade 1870 to 1880, some outstanding work on life histories and habits of grasshoppers in general was done by C. V. Riley, A. S. Packard, and others. In 1883 Packard (*11*) worked out the embryological development of *atlanis*. Since that time this species has been mentioned in much of the literature pertaining to control methods and to the grasshopper fauna of the United States.

GEOGRAPHICAL RANGE

Melanoplus atlanis is indigenous to the North American Continent and has a greater geographic range than any other species of this large genus. According to Hebard (*6, p. 112*), the species

> * * * is generally distributed over all but the tropical lowlands of Mexico, reaching northward over all the United States except peninsular Florida and California west of the Sierra Nevada Mountains, to southern Canada, having also been reported from the Yukon River, Alaska [this latter record, we believe, requires verification]. On the Pacific Coast, however, in British Columbia as far north as the Chilcotin District, it is very abundant and widely distributed.

In the New England States, according to Scudder (*28*):

> It is found everywhere from the seashore to the tops of the highest mountains of New Hampshire, being tolerably common on the summit of Mt. Washington, whence it has been brought by numerous persons.

Fernald (*4*) states that this is a common species throughout New England. It has been found in the Southeastern States breeding from sea level to the summit of Roan Mountain, N. C. (6,300 feet) (*9*), and in the Boreal, Transition, Upper Austral, Lower Austral, and part Sabalian, in Maryland, Virginia, North Carolina, South Carolina, Georgia, and northwestern Florida (*16, 19, 21*). It is a very common species in all of the Southern States and often locally abundant. Blatchley (*1, p. 414*), says "This is a very common locust throughout Indiana." In the Southwest it has been taken in central Mexico (*13*), in the Sacramento Mountains, New Mexico, at 6,500 feet elevation (*12*), and in Arizona (*14, 15, 18*). In the Middle Western States and Canada (*17, 20, 30, 31*) and Pacific States, it is frequently abundant over large sections. In 1877 Scudder (*28*) took it in the American Fork Canyon, Utah, at 9,500 feet. He also says (*26*) that it has been collected at Glen Brook, Nev., Wallula, Wash., Portland, Oreg., and Victoria, Vancouver Island. On July 20, 1901, a specimen was taken by Caudell (*2*) and Dyar on the snow fields on the summit of Pike's Peak, Colo. Several specimens were taken in August, 1925, in Pingree Park, Colo., at an altitude of about 9,000 feet. All this indicates the immense range of this one species. According to Hubbel (*8*), this species is probably the most abundant grasshopper occurring in North Dakota and surpasses all other species in destructiveness in that State.

VARIATION

Melanoplus atlanis is one of the most variable of the Melanopli, so much so as often to be quite indistinguishable from its immediate allies. The New England form of the species is distinctly smaller than the western or southwestern form (*18*). According to Scudder (*27, p. 183*):

> Specimens from the dry plains of the West (especially noted in those from Utah) are decidedly paler and more cinereous in aspect than those from relatively fertile country, and they have often a flavous stripe bordering the eye and continued along the position of the lateral carinae; a similar but not so striking a cinereous hue attaches to those that occur in sandy localities in the Eastern States, as along the sea margin. The exact contrary is shown in

Canada just east of the Rocky Mountains, where the specimens are exceedingly dark in color, almost blackish fuscous, with heavy fasciation of the hind femora [specimens from Sudbury, Ontario, are similarly dark]; but here again a difference of another sort occurs as one passes eastward, specimens from Laggan and Banff almost invariably having relatively long and slender male cerci, while at Calgary all that have been seen (with a very few from the former localities) have male cerci hardly more than half as long again as broad. Specimens from Mexico, however, agree very closely with those from New England.

Scudder continues:

Specimens with green hind tibiae have been seen by me from the White Mountains, New Hampshire, but not from the summits (except Kearsage, 3,251 feet), from the vicinity of Boston, at Provincetown, and on the island of Nantucket, Massachusetts, from Laggan, Alberta, the Yellowstone Region, Montana, Wyoming, Nebraska, Missouri, Colorado, from the Salt Lake Valley and American Fork Canyon (9,500 feet), Utah, Texas, and Chihuahua, Mexico. Specimens with dark blue hind tibiae have been seen from Iowa, Colorado, American Fork Canyon, Utah, and Texas. In nearly or quite all these places specimens with red hind tibiae predominated in the same district.

In the typical material of Saussure from Mexico for *M. mexicanus mexicanus*, Hebard (*5*) found that the "individuals show both red and glaucous caudal tibiæ, the glaucous type being much more frequently encountered in Mexico than in the United States."

In South Dakota, Hebard (*6, p. 112*) noticed that "in the more humid sections of the State the great majority have the caudal tibiæ pink, very few having these members pale glaucous. In the more arid sections, the reverse is true."

All of Walker's (*30*) specimens from Ontario "have the typical red hind tibiæ" nor has he "ever noticed a specimen with tibiæ glaucous or otherwise differently colored." The following color variations are also found among those individuals collected in northern Montana: The general color varies from a blackish fuscous to a greenish gray; a heavy fasciation of the hind femora to a whitish green; caudal tibiæ from blue to red; epicranium from a dark reddish brown to pale blue green; prothoracic shield along median carina from a yellowish hue to dark gray, almost black; black markings along the lateral carina from well marked to rather faintly marked.

Specimens from identical localities in northern Montana show considerable individual variation in size and tegminal length, while the coloration shows the usual variation of this species. As an illustration of the difference in size found among representatives from this part of the State, measurements of one of the smallest and one of the largest specimens are given. Of the smallest, the length of the hind femora is 11 mm., length of tegmina 16 mm., and body length over all to tip of tegmina 21.5 mm. Of the largest, the length of the hind femora is 15 mm., length of tegmina 22 mm., and body length 29 mm. Even though specimens of all sizes can be found, individuals collected from the same locality for a period of years indicate that the mean size has varied from year to year. Furthermore, it has been observed that during the years when the worst outbreaks and damage from grasshoppers occurred, the members of this species were larger than they were during the years when few or no outbreaks took place.

HABITAT

While this species extends over a wide territory, in the main it is partial to light sandy soil containing very little humus. In New York State it breeds most abundantly in localities having light, sandy soils, often characterized by sandy knolls and ridges and thin bare pastures (*7*). These localities are most suitable for the growing of rye and oats. It is frequently found in dry grassy fields, abandoned farms, and fields of the Southern and Southeastern States (*10*, *21*). In the Northwestern States and Canada this species is common on the sandy prairies, dry fields of grass and sagebrush, and grainfields.

In parts of Montana the preference for light, sandy soils, evidenced by this grasshopper, is very well illustrated. In Judith

FIGURE 1.—Wheat-stubble field, ideal breeding ground for *Melanoplus atlanis*

Basin County the soil varies from a heavy clay or gumbo to a light sandy loam within short distances. Invariably *Melanoplus atlanis* is scarce on the gumbo, but numerous and dominant on the sandy soil. In these sandy loam districts, when numerous, it is especially abundant along fence rows and in the wheat-stubble fields (fig. 1) where there is a thick growth of Russian thistles. In stubble land it is very abundant in low, weedy places where the Russian thistles or wild rosebushes grow thickly. Other plants common to these places are curled dock (*Rumex crispus* L.), plantain (*Plantago major* L.), and sagebrush (Artemisia). In mountain country it is most abundant on low, grassy hills and parks covered with grama, western needle (Aristida), bluejoint (Calamagrostis), and spear grasses (Stipa). On rolling prairie land it is most numerous where the grass is tall or in coulee bottoms. (Fig. 2.)

ECONOMIC IMPORTANCE

Though this species is found in nearly all of the States, its greatest damage has been done west of the Mississippi River, and especially in the northern, hard spring wheat area, including the Provinces of Canada from Manitoba westward.

It is quite probable that this species was responsible for the outbreaks of grasshoppers that have been mentioned as occurring in various parts of New England periodically for over 170 years, or since 1743. Severe outbreaks occurred in New York State in 1914 and 1915 (*7*). The grasshopper outbreaks in Michigan have been

FIGURE 2.—Rolling prairie land where spear grass (Stipa) is the dominant plant and *Melanoplus atlanis* the dominant grasshopper

caused largely by this grasshopper. For many years in Minnesota this species has been one of the chief species concerned in the outbreaks. Other States in which it has occurred in great numbers at various times are Nebraska, Colorado, Kansas, and Oklahoma. Unusually severe outbreaks have also occurred in many of the Provinces of Canada.

In North Dakota and Montana its outbreaks have at times been unusually widespread and destructive. It was the principal species present during the outbreak of 1919 in North Dakota, when the State spent $604,000 to combat this and other grasshoppers. In Montana, in 1923, the outbreaks reached the peak as regards extent and damage (*3*), and the severe losses from the hordes of *M. atlanis* recalled the earlier ravages of the Rocky Mountain locust in 1875

FIGURE 3.—Wheat defoliated by *Melanoplus atlanis*

FIGURE 4.—Inroads made by *Melanoplus atlanis* in a field of flax

and 1876. Fields of wheat, oats, flax, and alfalfa were wholly destroyed. In northern Montana the crops in most places were a total loss. The grain plants over entire fields have been eaten to the ground, defoliated, or beheaded (fig. 3); fields of flax have been eaten bare (fig. 4); alfalfa stands totally destroyed or kept gnawed to a height of about 4 inches; and shade and fruit trees defoliated. Upon good authority it has been reported that during the worst grasshopper years, on the streets of the towns in northern Montana, women experienced much difficulty in that the grasshoppers flew under their rather long and voluminous skirts, which were commonly worn at that time, causing them much discomfort and forcing them to disrobe upon their return home in order to dislodge the more venturesome of these migratory pests. Many are the stories that have been told concerning grasshopper outbreaks until a sort of tradition has grown up about them.

LIFE HISTORY

THE EGG

The egg of *Melanoplus atlanis* is whitish yellow or cream colored, elongate oval, slightly curved, the posterior end pointed and with a distinct cap, while the anterior end is bluntly rounded. The chorion is densely hexagonally punctate, the cap being more densely punctate than the rest of the chorion except at the tip, where it is smooth. The length of the egg ranges from 4 to a little over 5 mm. with an average of 4.5 mm. The width ranges from 1 to 1.5 mm. at the widest part. These figures are based on measurements of 100 eggs selected at random. The chorion becomes dry and brittle and splits longitudinally. The number of eggs in a pod is from 8 to 20, and possibly more.

In Montana the eggs of this species are usually found about 1 to 2 inches below the surface in light sandy loam, along fence rows protected by Russian thistles, around the base of wheat stubble or alfalfa, and seldom in adobe or heavy sod. Where the soil is a sandy loam another favorite place is around the edges of straw stacks protected by Russian thistles or a thin matting of rotted straw. (Fig. 5.) In the neighborhood of these stacks there often occur half buried flat stones around the edge of which the egg pods are found deposited. Other favorite places are near grain or alfalfa stacks and in the crowns of wheat, alfalfa, or grass plants. As a rule egg pods of *M. atlanis* are found in scattered colonies and are not bunched, but in the case of heavy infestations as many as 18 pods have been found at the base of a single wheat plant.

Eggs of this species collected in Montana during the fall of 1925 showed a very advanced degree of embryological development. The eyes, mouth parts, legs, antennæ, segments of the abdomen, etc., were plainly visible through the embryo sac after the chorion had been removed. They hatched within three days after incubating at a constant temperature of 85° F. Packard (*11, p. 273*) made the following observation on material received from C. V. Riley, consisting of "eggs of *C. atlanis*, laid 10 days":

> These eggs were laid in the autumn, and the embryos, as seen by the following account, were already far advanced, the body-segments and appendages having

appeared, the eyes being indicated, the brain and nervous cord being well formed and the œsophagus and crop (stomodæum) and hind gut (proctodæum) being indicated * * *

This shows that the development in the eggs of those locusts which deposit their eggs in the autumn goes on rapidly, and that the embryo is nearly perfectly formed and about ready to hatch in the early autumn * * *. At all events, it is proved by finding the embryos so far advanced ten days after oviposition, that development begins as soon as the eggs are deposited, and that the embryo is nearly perfected and about ready to hatch, until the approach of winter arrests the final stages of development of the embryo, a few warm days in spring enabling it to complete its growth and to hatch.

Heat and moisture are absolute necessities for the development of the embryo. In order to incubate eggs in the laboratory, it was found that the sand in which the eggs were placed must be kept moist. If it became dry, they shrivelled, and the embryos were destroyed. In

FIGURE 5.—Old straw stack. The soil around the edges of such stacks is a favorite place for deposition of eggs by adult females of *Melanoplus atlanis*

rearing grasshoppers in the laboratory, it was found that incubating eggs of *Melanoplus atlanis* at temperatures of from 80° to 85° F. produced the best results because the greater percentage of the eggs hatched in a relatively short time and the resulting nymphs were more vigorous. One observation in the field during a general hatching period covering about two weeks showed that the maximum soil temperature at egg depth ranged from 70° to 91°. During this period the soil temperature remained from 6 to 20 hours per day above 70° and averaged not more than four hours per day below 60°, the point below which the progress of hatching was arrested.

Unhatched eggs were observed remaining in the soil that was shaded by growths of Russian thistles in stubble fields or by a thin matting of straw around straw stacks for periods of from two to three weeks after general hatching had taken place. Temperatures of the shaded and unshaded soil, taken at the same time for several

days, showed a difference of about 10°, the temperature of the former ranging from 60° to 68° F., and the latter from 70° to 80°. Invariably the eggs in the bare or exposed soil had hatched, while those in the shaded soil were still unhatched. This explains, in part at least, the fact that the hatching of eggs of *M. atlanis* extends over a period of several weeks. The observations indicate that the minimum hatching temperature is between 60° and 65° and the optimum from 80° to 85°.

THE NYMPHAL STAGES

The number of instars occurring in the specimens of *Melanoplus atlanis* reared through to maturity in the laboratory ranged from five to six. This variation in the number of instars has also been observed in the field.

METHOD OF STUDY

In the study of the development of this species in the laboratory, a general method was developed which is being used in working out the life histories of all the other grasshoppers which are being studied by the writer. The eggs of this species were gathered in the field during the fall and kept in cold storage until needed. They were then placed in moist sterilized sand in suitable receptacles and kept at a constant temperature in an incubator. For this species this temperature was about 85° F.

As the nymphs hatched out they were placed separately in 1½-inch glass tubes 8 inches long and fed from day to day on a varying diet of lettuce, alfalfa, and wheat sprouts. Each glass tube was covered at one end with a piece of scrim, and the other end was plugged with a cork having a hole bored through it and covered with copper screening. The nymphs were kept at a room temperature which ranged from 75° to 85° F. during their whole development. Each day the tubes were examined for cast skins of the nymphs, and when these were found a record of the date was written on the tube with a china pencil. Specimens, both male and female, of each instar were photographed, and drawings were made of the lateral view of the thoracic segments and the dorsal and lateral views of the posterior end of the abdomen. In each instar, measurements were made of the length and width (widest part) of the hind femora and the length and number of the segments of the antennæ.

The results given in this bulletin are based on the rearing of some 250 individuals of this species in the laboratory at various times in conjunction with field observations over a period of four years.

KEY TO THE INSTARS

This key includes only the most conspicuous characteristics of the various instars in the development of *M. atlanis* up to and including the adult stage. It is applicable to specimens having either five or six instars, as the sixth or extra instar occurs after the third molt and in the key is inserted between the third and fourth instars of the 5-instar grasshoppers. The fifth and sixth instars of the 6-instar grasshoppers are structurally the same as the fourth and fifth instars, respectively, of the 5-instar specimens.

a. Wings and fully developed leg [illegible] ..... Immature forms or nymphs

b. Wing pads not turned up but pointing down

c. Wing pads [illegible] thoracic segments bluntly rounded at apex

d. Length of hind femur 2.5–2.5 mm. [illegible] antenna 11 to 12. Median carina of prothorax knifelike, giving the pronotum a ridgelike appearance, supra-anal plate bluntly rounded at apex; cerci very prominent; podical plates less conspicuous dorsally (fig. 6). ..... First instar.

dd. Length of hind femur 3.2–3.3 mm. [illegible] antenna 14 to 16. Median carina not so knifelike, prothorax fuller and more rounded, not ridgelike; supra-anal plate more pointed; cerci not very prominent; podical plates more conspicuous dorsally (fig. 7). ..... Second instar.

cc. Wing pads externally [illegible] thoracic and metathoracic segments, [illegible]

d. Length of hind femur 4.3–5 mm. Number of segments of antenna 17 to 18. Small; wing pads pointing almost straight down, broader and not so pointed at apex, showing a slight venation. Molted three times (fig. 8). ..... Third instar.

dd. Length of hind femur [illegible] mm. Number of segments of antenna 19. Large; wing pads pointing more obliquely backward, narrower and rather pointed at apex with venation well defined. Molted four times (fig. 11). ..... Fourth instar.

bb. Wing pads turned up

c. Length of hind femur 5.7–7.1 mm. Number of segments of antenna 19 to 20. Wing pads short, extending only beyond the middle of the first abdominal segment (fig. 9). ..... Fourth instar.

cc. Length of hind femur 7.8–9.7 mm. Number of segments of antenna 21 to 22. Wing pads elongate, extending beyond the second or third abdominal segment (fig. 10). ..... Fifth instar.

aa. Wings fully developed and tegmina extending to or beyond tip of abdomen, genitalia fully developed (fig. 12). ..... Adult stage.

DESCRIPTION OF INSTARS

The following is a description of each instar of *Melanoplus atlanis*, based on studies of individuals reared in the laboratory. The temperature ranged from 75° to 85° F., and the relative humidity was approximately 20 per cent. A separate study of the individuals that developed six instars was made and is treated as a special subject in the description of the extra instar.

FIRST INSTAR

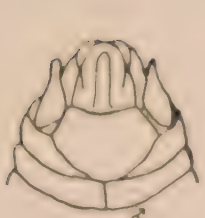
Immediately after hatching the nymphs are pale in color but soon become generally a mottled blackish. (Fig. 6.) A light stripe begins below the eye and curves upward along the jaw below the lateral carina, and a faint stripe follows along the median carina. The head frontals are inclined dorsally. The total length of the newly hatched nymph is about 4 mm., but the abdomen becomes fuller and more elongated as the instar progresses. The length of the antenna averages 4.2 mm., and the number of antennal segments ranges from 11 to 12. The length of the hind femur averages 2.4 mm. The wing pads [illegible] by the mesothoracic and metathoracic segments are indistinct and rounded at the apex, and seem to be a part of the segmentation of the thorax. A pointed appearance is given to the prothoracic shield by the knifelike aspect of the median carina. At the posterior end of the pronotum the carina extends to and a little beyond the apex of the segment plate, being large and conspicuous in proportion to the rest of the parts; the supra-anal plate is plainly

resemble at first sight. A difference in sex can be distinguished only with a lens. The rudimentary subgenital plate of the male and the dorsal valves of the ovipositor of the female help very much alike and are easily overlooked, owing to the deeply notched subgenital plate. However, there can be found two small lobes or projecting ventral valves of the ovipositor besides from the eighth abdominal segment. (Fig. 6, G.)

The number of days included in this instar ranged from 4 to 15, with an average of about 8.

FIGURE 6.—The lesser migratory grasshopper, first instar. A, Female, ×5.4; B, male, ×5.4; C and D, dorsal and lateral tip of abdomen of female, ×15; E, lateral view of thoracic segments, ×15; F and G, dorsal and lateral view of tip of abdomen of female, ×25.

In general the second-instar nymph is about half again as large as that [illegible] and is darker and has a more [illegible] than the [illegible] (fig. 7, A). The prothorax is more rounded laterally



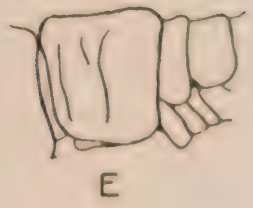


FIGURE 7.—The lesser migratory grasshopper, second instar. [illegible] male, × 5.45; C and D, dorsal and lateral of tip of abdomen of male, [illegible] lateral thoracic segments, × 14.1; F and G, dorsal and lateral of tip of [illegible] of female, × 30.6

and have no pointed appendages as the molting suffix becomes less definite. The mandibulate and maxillipedate segments remain prominent at the bottom, but the wing pads begin to bulge in such a manner as to be slightly visible externally in proportion to the other parts of the body of the abdomen the cerci of both sexes and females have become somewhat and are not very prominent. The supraanal plate is more pointed at the apex. The sex is easily distinguished, the subgenital plate of the male and the valves of the ovipositor of the female being readily perceived. The length of the hind femur averages 3.3 mm., the length of the antenna averages 4.8 mm., and there are from 14 to 16 antennal segments.

The number of days required for this instar ranged from 5 to 12, the usual number being 6.

THIRD INSTAR

The average size of the third-instar nymph is about twice that of the first instar (Fig. 8.) Wing pads for the first time are plainly visible, pointing downward and showing a slight rotation. Body markings are more distinct and remain about the same during the rest of the nymphal development. The subgenital plate of the male and the valves of the ovipositor in the female extend well up toward the apex of the segmented legs. The length of the hind femur averages 4.7 mm. and that of the antenna 5.8 mm., and the latter have 17 to 18 segments.

The number of days required in this instar ranged from 5 to 30, the most frequent number being 6.

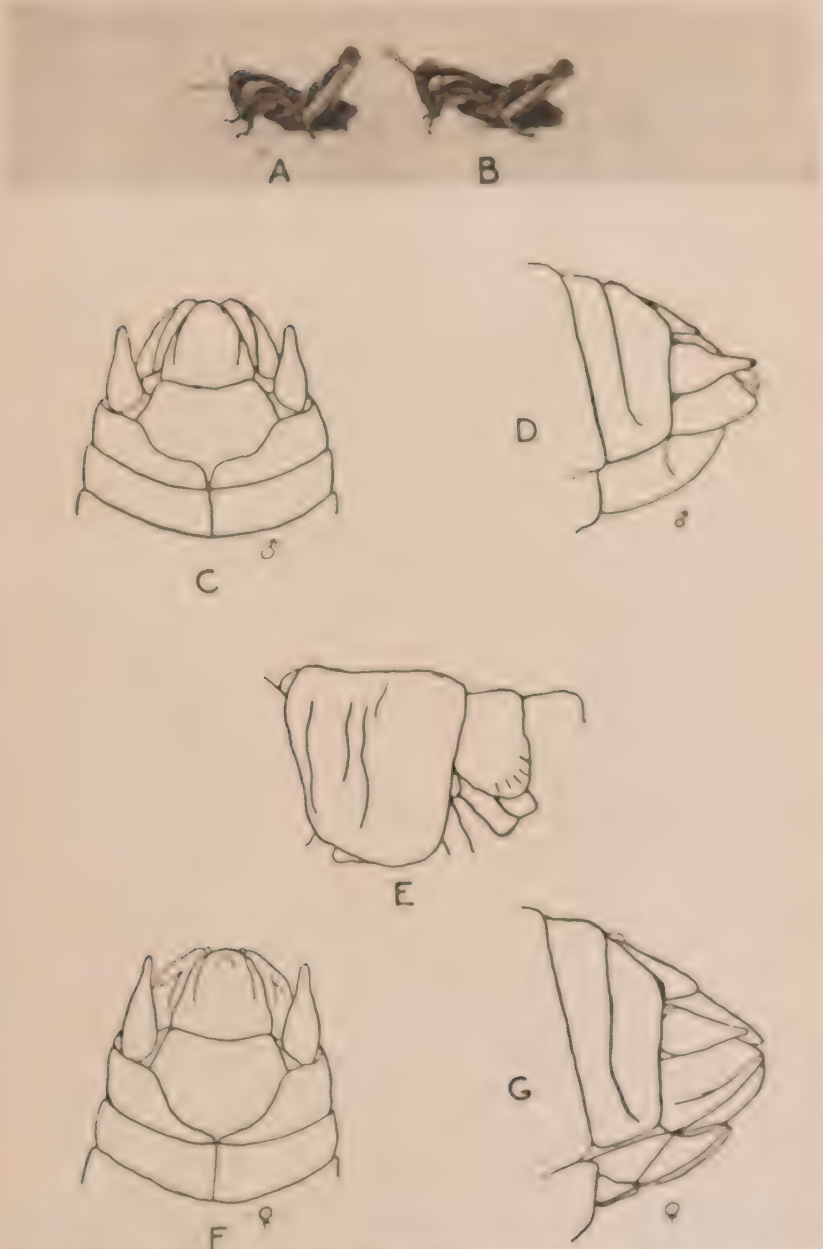
FOURTH INSTAR

Normally, in the fourth instar, the wing pads are turned upward for the first time and extend well back toward the middle of the first abdominal segment, and there is a well-defined rotation. (Fig. 9.) Individuals whose wing pads are turned upward in the fourth instar undergo few changes in their nymphal development. Very often, however, the wing pads of male specimens are not turned upward after the third molt, but remain pointing downward, as in the female nymphs shown at the left in the photograph of the fourth instar. (Fig. 9, A.) Such individuals undergo six instars. A careful study of these has been made and recorded in the paragraph describing this connection. The total length of the normal nymphs which undergo five instars is about 11 mm. at this stage of development. There are either 19 or 20 antennal segments, and the antenna averages about 9.1 mm. in length. The hind femur is about 5.7 mm. long. For the first time in the male the furculae are visible, and the subgenital plate extends beyond the apex of the supraanal plate. In the female the valves of the ovipositor extend farther toward the apex of the supraanal plate. A dorsal view of the posterior end of the abdomen of both sexes shows the pedeal plates extending beyond the tip of the supraanal plate and broadly triangular.

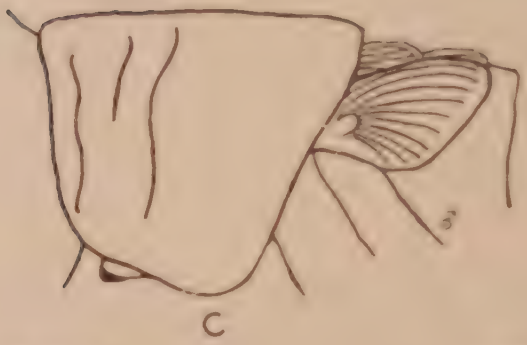
The number of days for this instar ranged from 5 to 11, with an average of about 7 days.

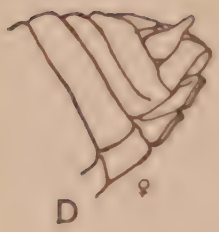
FIFTH INSTAR

This description applies to the fifth instar in individuals undergoing only five instars. The wing pads are more elongated than in the fourth, and extend backward beyond the third or fourth abdominal segment. (Fig. 10.) The total length of the grasshopper in this instar is about 14 mm. There are from 21 to 22 segments in the antenna, the length of which averages 5.8 mm. The length of the hind femur averages approximately 8.9 mm. In the male the subgenital plate extends well beyond the supraanal and pedeal plates, the furculae are well developed, and the cerci are much more flattened and each is shaped more or less like a hook. In the female the valves of the ovipositor extend beyond the supraanal and pedeal plates, but the cerci are more rudimentary.



male. C, D, E, F and G, female. C and D, dorsal and lateral of thoracic segments, × 13.6; F and G, dorsal and lateral of tip of abdomen of female, × 31.0





of tip of abdomen of male. ×15.5

The number of days required for this instar is from 6 to 10, with an average of about 8 days.

Exceptions to the foregoing descriptions are found in those individuals which go through six instars. These particular specimens, except for size, show a regular fourth-instar development upon emerging at the fifth instar. In size they are about as large as specimens in the fifth instar at this stage. The female at the left in the photograph of the fifth instar has molted four times but shows only fourth-instar development, though it is nearly the same size as the regular fifth-instar male shown on the right. (Fig. 10, A.)

EXTRA INSTAR

An effort was made to determine at what point in the nymphal development of this species the extra instar occurs. Twenty-five newly hatched nymphs were placed separately in glass tubes as previously described, and fed from day to day. After each individual had entered each successive instar, it was carefully examined under a binocular microscope in order to ascertain whether it showed any marked difference in size or characteristics from others of the same instar.

It was already known that all individuals of this species invariably have their wing pads turned upward in the last two instars before reaching maturity. This applies to all species of grasshoppers so far as is known. No structural differences are shown during these last two instars whether five or six instars occur. Therefore, when the extra instar does occur, it must appear before what would be the fourth instar, if there are only five instars in all, or before the fifth instar, if there are six. In view of this fact, it was necessary to make a careful study of only the first three instars.

At this point a verification of the use of this method would confirm the results of the experiment. In planning the work for this particular experiment, there were certain things that could reasonably be expected at the outset, and these were as follows: Of the 25 specimens to be reared for study it was believed that some would undergo five instars and some would develop the sixth or extra instar, before reaching maturity. Furthermore, those that underwent five instars should show the same structural development among themselves throughout the whole nymphal period. This similarity could also be expected among those that underwent six instars. Finally, the extra instar must occur between the hatching of the egg and the regular fourth instar for reasons set forth in the preceding paragraph.

With these facts upon which to base the rest of the procedure, the reasons for using this method are as follows: Should the extra instar occur before the first molt, then, of the 25 newly hatched nymphs, those that were undergoing this extra instar must show some difference in structure and size from those that were undergoing the normal or 5-instar development. Otherwise it could not be called the extra instar. Should this extra instar occur between the first and second molts, then after the first molt those that were experiencing this extra stage would show some differences from those regularly in the second instar and undergoing five instars.

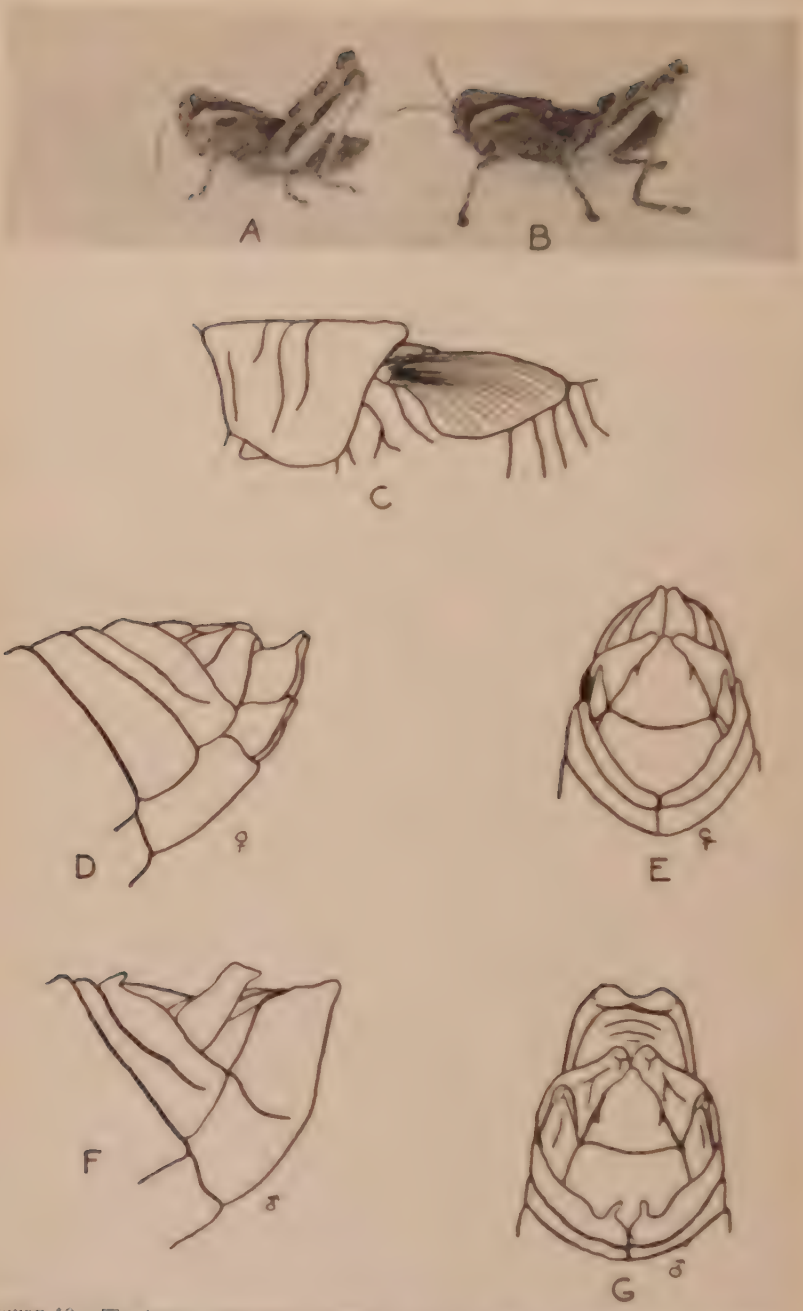


FIGURE 10.—The lesser migratory grasshopper, fifth instar. A, female, ×2.3; sixth-instar individual, showing fourth-instar development after molting four times; B, male, ×2.3, showing [illegible]; C, lateral of thoracic [illegible]; D and E, lateral and dorsal of tip of abdomen of female, ×15.1; F and G, lateral and dorsal of tip of abdomen of male, ×15.1

This same reasoning holds true throughout the rest of the development. Therefore, if any individual, or group of individuals, after hatching or after any given molt, shows for the first time a consistent difference from the remaining specimens that have molted the same number of times, and the individual or group showing this difference undergoes six instars and the other group undergoes five, then it can be said that the extra instar occurs at this point in the nymphal development of the species.

There are three arguments that could be used against such reasoning. One is that the extra instar may have occurred after molts previous to the one after it was first noticed, and may have escaped observation because the differences were so slight. Or perhaps there is no definite extra instar, but rather a modification of all the instars. The third argument is that this extra instar is fortuitous in that it may occur at any point of the development and that the proof of the conclusions reached in this study should be strengthened with more material and more data. However, the results were so outstanding as practically to preclude all these arguments.

The following method of reasoning and procedure was used in the study of the development of the 25 specimens: It was found that structural differences and a difference in size were first noticeable after the third molt. Up to this point the development had been practically the same in all cases. The normal 5-instar grasshoppers had their wing pads turned upward after the third molt, whereas the rest of the specimens did not. After the third molt the wing pads of these latter nymphs still pointed downward and differed from any of those still in the third instar in that the wing pads were more elongated, were pointed, and showed a more distinct venation. (Fig. 11, C.) These individuals also were much larger than the third-instar nymphs, being nearly of the same size as those whose wing pads were turned upward and who were in the normal fourth instar. Invariably they underwent six instars, the fifth and sixth of these being structurally the same as the fourth and fifth instars, respectively, of the 5-instar nymphs. The extra instar, therefore, occurs after the third molt or between the regular third and fourth instars.

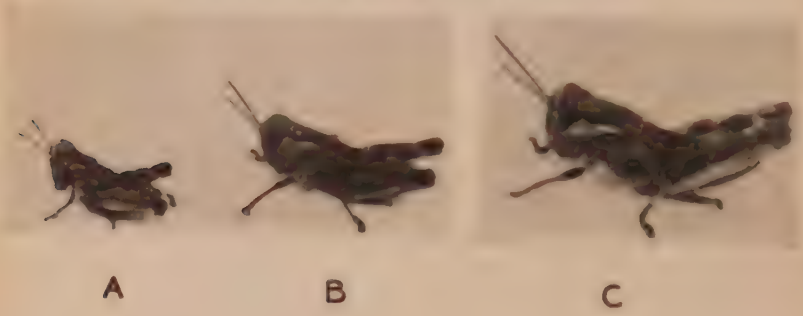
These facts are well illustrated by the photograph and drawings depicting this phenomenon. In Figure 11, from left to right, the three specimens are as follows: A is a normal second-instar nymph; B is a normal third instar nymph; C is a nymph whose wing pads did not turn up after molting three times and which does not show any of the fourth-instar characteristics except for general size, and is in the extra instar. The drawings show the development of the wing pads in the second, third, extra, and fourth instars, indicating the difference between the third and the extra instar.

Measurements of specimens in the extra instar indicate that they are intermediate in size between the regular third instar and regular fourth instar representatives. There are 19 segments in the antennæ, which is about 3.25 mm. long. The length of the hind femur averages about 5.92 mm.

Measurements of extra-instar nymphs indicate that in the fifth and sixth instars they are larger than the normal fourth-instar and

fifth instar nymphs, though structurally the same. These points are brought out in the summary of measurements given in Table 1.

The extra instar averaged about 9.4 days in length, and individuals that undergo six instars have a greater average number of days in their nymphal development than do those undergoing five, the average time being 41.4 and 35 days, respectively.



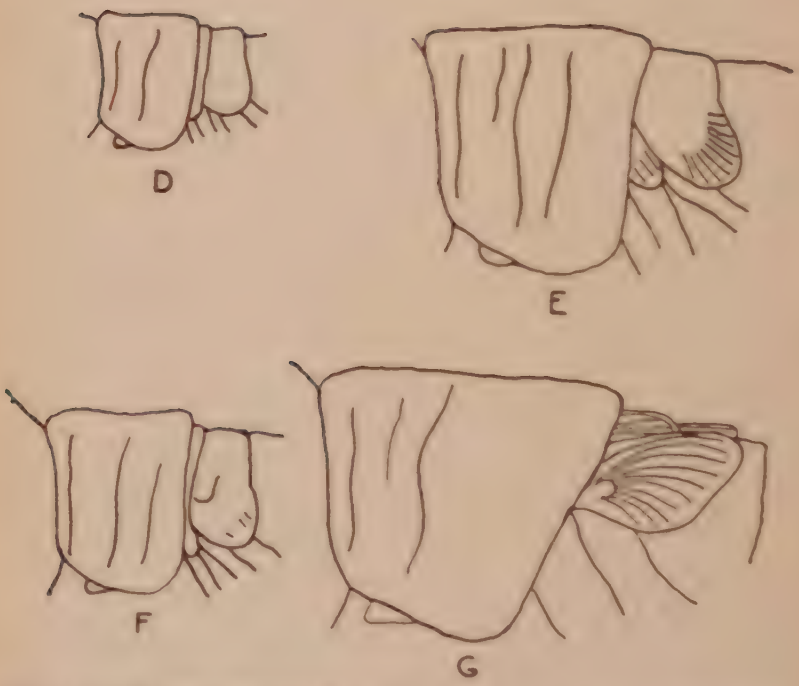


FIGURE 11.—The lesser migratory grasshopper, extra instar. A, Second instar, molted; B, third instar, molted; C, fourth instar, molted; D, fifth instar, nymph; E, sixth instar, molted; F, extra instar, molted; G, seventh instar, nymph. D, E, F, and G, Variations of thoracic segments of second, extra, third, and fourth instar nymphs, respectively. ×13.6

TABLE 1.—*Summary of measurements during nymphal development for grasshoppers of Melanoplus atlanis having the normal number of instars and that have formed two extra instars*

Instar	Duration of instar		Length of hind femur		Width of hind femur		Length and width of hind tibia	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
	Days	Days	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.
1	15	15	1.90	1.90	2.30	2.30	1.60	1.60
2	18	18	2.80	2.80	3.71	3.71	2.42	2.42
3	20	19	4.20	3.85	6.56	5.95	3.80	3.45
4	22	22	5.83	5.72	9.06	7.62	5.25	5.17
5		32		8.51		9.21		7.98

THE ADULT

The last or adult stage (fig. 12) is reached after the fifth molt in grasshoppers undergoing five instars and after the sixth in those developing six instars. Molting usually takes place during the warmest hours of the morning. As soon as the adult has become detached from the old skin, according to Riley [144, p. 256], in his description of the last molt of *M. spretus*,

> The front wings are at first held longitudinally as a hood, and, as they expand and unfold, the hind wings, which are folded and pleated under the veins, at first curl over them. In ten or fifteen minutes from the time of extrication these wings are fully extended and hang down like dampened rags. From this point on the hind and wings begin to fold up like fans beneath the narrower front ones and in another ten minutes they have assumed the proper attitude of rest.

The pale color soon gives way to the final tints.

The median carina of the pronotum is crossed transversely in the principal sulcus, which forms a deep groove. In the male the subgenital plate of second and third segments is produced far beyond the apex of the supranal plate, and forms the lobes of the ovipositor. During the earlier stages of development the subgenital plate, from the manipulation of exterior parts by the other parts and the supranal and anal pedical plates, which compose the tip of the abdomen, is held somewhat under the subgenital plate in proportion to the other parts until at maturity it is by far the most prominent. The pedicel is not plainly visible in the form of a ridgelike structure, covered with a soft tissue, lying within the cavity of the subgenital plate that incloses the apex of the supranal plate. The anal of the male have developed long, curved appendages into broad flattened stipites, finely wrinkled, tuberculate apically. The hamuli are more or less divergent, forming slight, slender, acuminate spines. In the female the valves of the ovipositor, inclosed in the subgenital plate of the male, have increased in relative size until they are almost half the length of the supranal plate or other exterior sensitive lamellae there, the dorsal valves curving upward, the ventral valves downward. The spurs on the fossulae have increased proportionately in size from prominences to long, tapering

REPRODUCTION

Copulation first takes place about two weeks after the adult stage is reached. In the case of a male and a female of this species reaching maturity on the same day, the period from the last molt to the first copulation was 17 days, under laboratory conditions. These were individuals copulated fourteen times. Once over a period of 28 days, being

in cotton seven times over a period of 15 days after the female had deposited the first egg pod. Twenty days after these individuals were first seen in cotton the female laid her first pod. She then oviposited ten times over a period of 25 days, the total number of

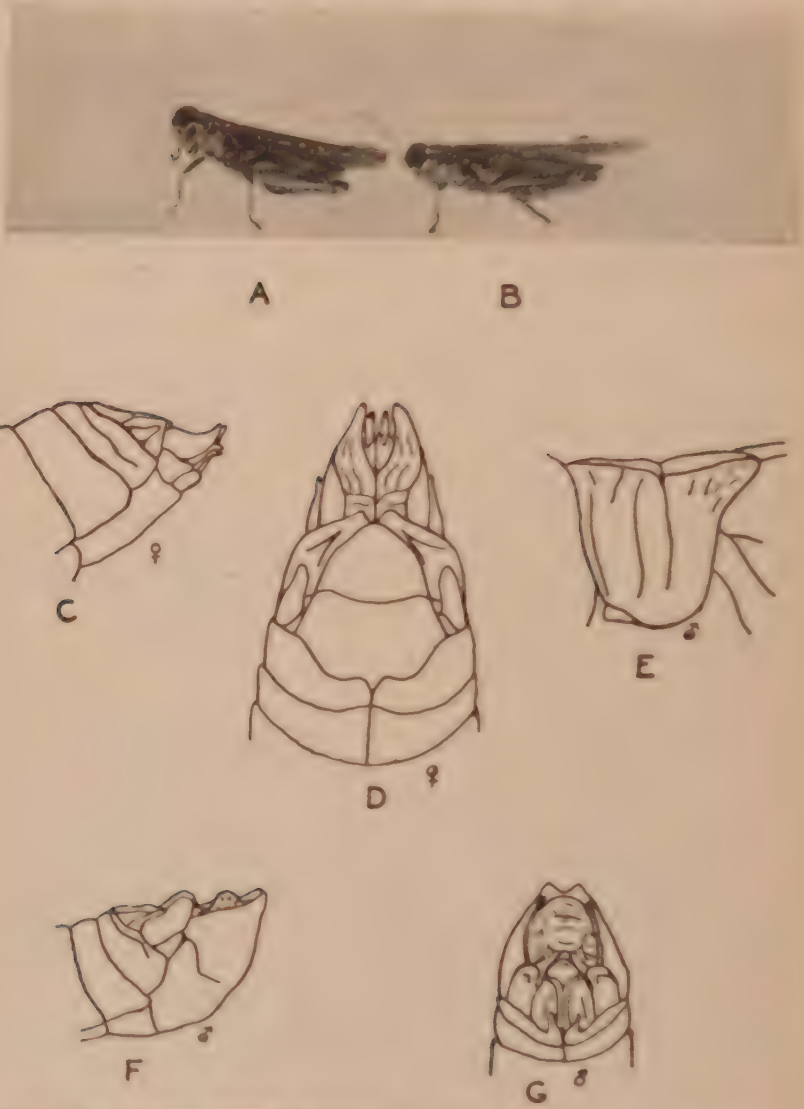


FIGURE 12.—The lesser migratory grasshopper, adult. A, female, ×1; B, male, ×1; C, lateral tip of abdomen of female, ×6.1; D, dorsal tip of abdomen of female, ×16.3; E, lateral of prothoracic shield of male, ×7.6; F and G, [illegible] of tip of abdomen of male, ×6.7

eggs being 197, or an average of about 20 eggs a pod. The female died 4 days after the last pod was laid, and the male lived 56 days after the last copulation. Altogether, the male lived 91 days and the female 76.

Oviposition usually takes place in firm soil of sandy loam under a covering of Russian thistles, or straw at the base of grain stubble, or in the crowns of alfalfa or native grasses. According to the observation made by Stewart Lockwood, at Billings, Mont., the time occupied in depositing one pod was 54 minutes, and in this pod were 19 eggs. In a discussion of the possibilities of increase of *M. spretus* (*Walk.*) it was recalled that in one female of spretus there were 50 ovarian tubes in each ovary, making 100 in all, each containing 10 rudimentary eggs, besides the nearly ripe ones. The females of the grasshopper now known as *atlanis* are no doubt just about as prolific, and under favorable conditions they can multiply very rapidly.

SEASONAL HISTORY

It is impossible to give exact dates or periods for the various events or stages that make up the seasonal history of *M. atlanis* in Montana, for these are governed each year by the weather conditions then prevailing.

In one locality in northern Montana in 1923 the peak of hatching was reached about May 1. In 1924 this occurred around June 1, in 1925 nearer the middle of June, in 1926 in the last week of April, and in 1927 in the latter part of June. The eggs are so far advanced in their embryological development in the fall that it requires only a week or 10 days of hatching temperatures to cause a general hatch. The term "hatching temperatures" means that during this period of a week or 10 days the soil temperature at the depth of the eggs must range above 70° F. for from 11 to 20 hours each day, reaching maximums of 74° to 90°, and averaging not more than 4 hours a day below 60°. However, in any particular year the hatching period may extend over a month or even six weeks, and may be expected to commence at any time from April 15 to June 15, depending upon the occurrence of such conditions as have just been described.

The length of the nymphal development also depends upon the weather conditions. In 1926, in northern Montana, fifth-instar nymphs were first observed June 3, but the majority of the grasshoppers were in the third instar. Collections made again on June 22 showed the majority still in the third and fourth instars, and no adults appeared until about July 5. The season was very late in 1927, and no adults appeared until about August 1. Ordinarily egg laying begins about the middle of August and extends on through September and October and into November, providing the weather permits.

Heat seems to be the important factor in all these activities. Hatching, nymphal development, copulation, and oviposition are all affected by the temperature in such a way that in no two years is the seasonal history the same.

MIGRATORY HABITS

NYMPHAL MIGRATIONS

When the young nymphs first emerge from the eggs they feed upon the nearest available plants, which in most cases in Montana are the native grasses or young tender Russian thistles. During

their early nymphal stages they seek shelter in the cracks in the ground or in weed patches, congregating at night or during inclement weather, and are active only during the warmer hours of the day when conditions are right.

At some time during the nymphal development they usually migrate in swarms into cultivated crops adjoining or near by. This migratory propensity, however, is seldom manifested during the first and second instars; all the observations of such movements made in Montana have shown the migrating nymphs to be in the third, fourth, or fifth instars. The migrations take place during the warmer hours of the day and do not last over six hours on any one day. The nymphs travel about 3 yards a minute (123, 211), and during this period of development they have never been known to disperse more than 10 miles from the place of hatching, and more often this distance is under 5 miles. The individual movement is first a run, then a hop, and then a rest. When a person walks into a swarm of migrating nymphs the young grasshoppers all jump in the same direction, which is the direction of the migration. When not migrating, however, they scatter in all directions when disturbed. This habit may be used to determine whether or not a migration is in progress and also to indicate its general direction.

As to the causes of migration, the only factor which seems to bear directly upon it is food. Practically all observations made in Montana have shown that the direction of the migrations has been toward more succulent and abundant food and usually has been from the hatching grounds toward the nearest available crops, regardless of direction of wind, sun, or points of the compass. This does not mean, however, that there are no external limitations on certain phases of these collective movements. Observations on nymphal migrations which occurred in northern Montana during June, 1926, indicated that there were external physical factors that limited the time in which this event took place. Of these limiting influences atmospheric temperature seemed to be of most importance. This is indicated by the results of the observations recorded in the paragraphs which follow. The atmospheric temperatures given were taken at an elevation of 3 feet, while the soil temperatures were taken at the surface of the ground with the bulb of the thermometer lightly but completely covered with dirt.

On June 5, 1926, a southward movement of nymphs, mostly in the third instar, began in a wheat-stubble field at 12 o'clock noon. At this time the air temperature was 75° F., and the temperature on the exposed surface of the soil was 85°. This migration ceased at 4 p. m. of the same day, at which time the air temperature was 74° and the soil temperature 90°.

The next observations were made of nymphs moving out of a 160-acre field into a neighboring wheat field across the road. At this time the wheat was about 6 or 8 inches high. This movement occurred during the warmer hours of the day, over a period of three days, June 7 to 9, inclusive. The general direction of the migration was toward the northwest corner of the stubble field, then north across the road into the adjacent southeast corner of the wheat field, the grasshoppers spreading out after entering the wheat. Most of the nymphs were in the fourth and fifth instars. On June

7 the beginning of the migration was not observed, but the movement ceased at 3 p. m., when the air temperature was 76° F., and the temperature on the exposed surface of the soil was 97°; the sky was cloudy and a stiff east wind was blowing. The nymphs congregated for the night in the heavy growth of Russian thistle in the road and along the fences. The next day the migration began at 10:30 a. m., when the air temperature was 82° and the soil temperature on the exposed surface was 107°, the sky being clear and a moderate southwest wind blowing. The cessation of this day's movement was not observed. On June 9 there occurred a notable migration due to fluctuating temperatures caused by alternate clear and cloudy skies. There was very little wind, just a slight breeze now and then. The nymphs were first noticed moving across the road at 10 a. m. About an hour later this movement had ceased altogether, even though conditions seemed not to have changed. Some explanation was sought for the cessation of this migration, and close observation for an hour showed a fluctuation of a few degrees in temperature with corresponding changes in the migratory movements of the grasshoppers. In order to facilitate the recording of exact temperatures at which any change in the progress of the migration took place, the observer sat at the edge of the road across which the grasshoppers were moving, with thermometers in easy reach. As before, air and soil temperatures were recorded and conditions of sky and wind were noted. The results are given in Table 2.

TABLE 2.—*Fluctuating temperatures and migratory movements of nymphs of Melanoplus atlanis, June 9, 1926*

Time	Event	Temperature of soil (1 inch, exposed)	Air temperature at nymphs' level	
			In shade	Exposed
9 a. m.		72	72	72
9:30 a. m.		74	74	74
10 a. m.		76	76	76
10:15 a. m.		78	78	78
10:30 a. m.		80	80	80
10:45 a. m.		82	82	82
11 a. m.		84	84	84
11:15 a. m.		86	86	86
11:30 a. m.	Movement increased	88	88	88
11:45 a. m.	General migration began	90	90	90
12 m.	Migration retarded temporarily	92	92	92
12:30 p. m.	General migration began	92	92	92

The fluctuation in temperature, and especially in air temperature, was due to alternate sunshine and cloudiness. While the sky was shining the air would be warmed and the grasshoppers would start moving. This would last a few minutes, and then a cloud would obscure the sun or a cool breeze would spring up. The nymphs would then cease moving. These observations and data indicate that the atmospheric temperature was the regulating factor of these movements. When this went below 68° F. migration ceased, but it was resumed when the temperature again attained this level. However, no general movement took place until the air temperature

reached 72°. This temperature checks very closely with the air temperatures observed at the beginning and end of the general migration of June 3, 1926, which occurred about 2 miles west of the scene of that just described.

MIGRATIONS OF ADULTS

The adults of this species migrate on the wing in large swarms over great distances. These migrations, or flights, as they are generally called, usually occur in the latter part of July or in August, but sometimes in September. Many theories have been advanced to account for these flights. Their cause really is unknown, although there are a few facts that might throw some light on the subject. These flights occur only when the species is abundant. This grasshopper is a very strong flyer and when disturbed in the field it often rises and flies 50 or 100 yards. During the heat of the day, on very hot days, these grasshoppers become very restless and will fly straight up in the air, several at a time, and circle around at elevations of 100 feet or more above the ground, gradually gathering until quite a swarm of them is flying around overhead. Perhaps they are trying to escape from the heat by seeking the lower temperature of the upper air. An abundance of sarcophagid or tachinid flies, their worst enemies, will also cause them to fly up into the air. When circling around in this manner they may be caught by currents in the upper air and carried off in the direction of the wind. Being strong flyers and being thus aided by the wind, they can travel great distances. During the summer of 1925 the flights observed in northern Montana were all toward the west. The following summer they were in the opposite direction. No major flights of this species have been reported in Montana since 1924. A flight was reported in western Kansas in September, 1927.

FEEDING

Members of this species do most of their feeding between 8 and 11 a. m. This is illustrated by the histogram for the average daily feeding, shown in Figure 13. The curve is derived from data obtained from observations made of grasshoppers, mostly *atlanis*,

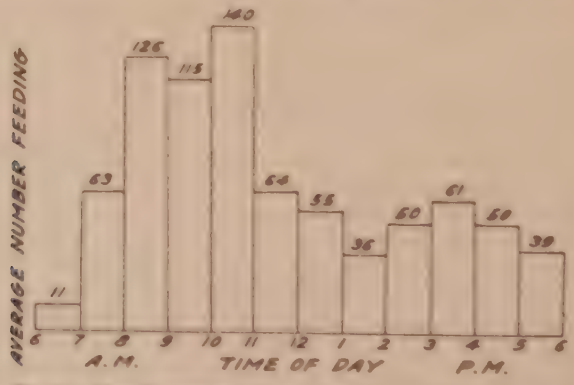


FIGURE 13.—Histogram of the average daily feeding of *Melanoplus atlanis*

feeding on samples of poisoned-bran mash used in experimental work with baits in northern Montana in the summer of 1924. In this work there were 32 days of observations, made in two different localities, viz, Havre and Cut Bank. This curve shows that after 11 a. m. the feeding declines until between 3 and 4 p. m., when it rises for a short time, declining again after 4 p. m. The conformation of this curve is probably due to the fact that the grasshoppers, after an all-night fast, move to satisfy their hunger, their feeding increasing as the morning advances and the air becomes warmer. After hunger has been satisfied feeding naturally declines and becomes more desultory during the rest of the day.

Other factors, however, also influence the feeding. Most of the feeding is done between the limits of 65° and 85° F. air temperature taken at an elevation of 4 feet, with optimum feeding temperatures between 70° and 80°. Little or no feeding takes place when atmospheric temperatures are above 90° or below 60°. The grasshopper can abstain from eating for several days and does so during periods of cold, cloudy, or rainy weather. One observation made at Havre, Mont., in June, 1924, showed the feeding to be four times as heavy on the day after a 4-day rainy period as on any day previous to it. More feeding is done when the sky is clear. During a moderate or stiff wind the feeding falls off or ceases entirely and is not resumed until the wind dies down.

The optimum feeding time, therefore, is from 8 to 11 a. m., when the sky is clear, when there is little or no wind, and when the air temperatures range from 70° to 80° F.

This species may be said to be almost omnivorous in its food habits, the diet depending of course upon the abundance of food. When famished, it will feed on fabrics, both cotton and woolen, dry and seasoned wood products, etc. It will also feed on its own species when individuals are weakened, as during the process of molting or when they are disabled in any way. However, they much prefer the more succulent plants such as growing wheat and alfalfa. They much prefer the green pods to the foliage of leguminous plants. They sometimes ruin an entire seed crop of alfalfa by biting into the seed curls and destroying the pod before it can develop. They also attack the wheat kernel while still in the milk or dough stage. Moist bran is very attractive to them in dry unirrigated farm lands, and this moisture is the only real attractant in the poisoned-bran formulas used to combat this pest.

ENEMIES

The most important predatory enemies of this insect in Montana are the lark bunting (*Calamospiza melanocorys*), western meadow lark (*Sturnella neglecta*), sparrow hawk (*Falco sparverius*), sage hen (*Centrocercus urophasianus*), sharp-tailed grouse (*Pedioecetes phasianellus*), and domestic turkeys and chickens. Of these the most important is the lark bunting, which is very abundant on the prairie lands. Swarms of grasshoppers can often be located by the presence of large numbers of these buntings. The Bureau of Biological Survey has found specimens of this locust in the stomachs of 24 species of birds.

Ground squirrels also prey upon these insects, and especially on the nymphs and can be observed running, jumping, and stamping after the young grasshoppers. Grasshopper mice also undoubtedly prey upon this as well as other species of grasshoppers.

Of the insect enemies, the digger wasps (Sphecidae) and robber flies (Asilidae) prey upon the nymphs. Many of the ground beetles (Carabidae) in both the larval and adult stages are predacious on the eggs. Others that feed upon the eggs are the larvae of the blister beetles (Meloidae) and of the bee flies (Bombyliidae). The important parasitic insect enemies are the tachinid and sarcophagid flies, parasitic on nymphs and adults, and the hymenopterous egg parasite *Scelio calopteni* Riley.

In his account of the action of tachinid flies in parasitizing grasshoppers Riley (23, p. 110–120) gives a description which can very well be applied to the methods of larviposition of the sarcophagid flies that are parasitic on grasshoppers.

[illegible] Tachinidae [illegible] which are oval, white, and [illegible] those parts of the body not easily reached by the jaws and legs of their victims and thus prevent the host from [illegible]. The egg-laying females are attached while living, and it is quite interesting to watch the insects' efforts when one of them, hooked by a [illegible] with [illegible] to elude its enemy. The fly usually [illegible] opportunity, and after the latter stops or turns she is at it and attempts to attach her egg under the [illegible] on the neck. The struggle frequently [illegible] and sometimes [illegible] several [illegible] accomplishing her purpose. [illegible] she has even greater difficulty; but though the latter [illegible] in all directions in its effort to shed her, she [illegible] ground [illegible] and generally succeeds in accomplishing her purpose, either while the insect is [illegible] or after it has [illegible] often just as it [illegible] from a flight or a leap. The [illegible] hatching from these eggs eat into the [illegible] of the insect, and after feeding on the [illegible] parts of the body—leaving the more vital parts untouched—they [illegible] and burrow in the ground, where they [illegible] to [illegible] pupate, from which the [illegible] either the same summer or next year. The [illegible] infested with this parasite is quite [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] as were [illegible] about the heather [illegible] [illegible] [illegible] shell filled with maggots, and so efficient is this parasite that the ground in parts of the Western States is often covered with the [illegible] dead and dying from this cause.

The sarcophagid fly *Sarcophaga kellyi* Aldrich, commonly called a flesh fly, lays living maggots on the grasshopper, which burrow into the body of the host and feed on the fatty parts. The maggots finally leave the body of the host and go into the ground to pupate. In northern Montana in the fall of 1924 the grasshoppers remaining after the control campaign control were very heavily parasitized by sarcophagid flies. As many as seven maggots were found in the body of one host. In the fields where the grasshoppers were numerous, but heavily parasitized, no grasshopper eggs were found.

In the fall of 1926 a small percentage of the eggs of *M. atlanis* in Hill County, Mont., were parasitized by *Scelio calopteni*. The first week in June of the following year the adults of this parasite were observed emerging from eggs of *atlanis*.

Other important enemies of *M. atlanis* are the hairworms, a species of the genus Gordius. They are found curled up within the body of the host, nearly filling it.

Two diseases are very destructive to this grasshopper at times; one of these is caused by a fungus, *Empusa grylli*, and the other is a bacterial disease.

All of the specific host relationships are common to most of the species of grasshoppers and are not peculiar to *M. bilineata*.

ECONOMIC BEARING OF THE INFORMATION OBTAINED

Aside from a purely academic standpoint, to what use can the information obtained in this study be put? A study of the geographical distribution of *Melanoplus bilineata* indicates an adjustability to a rather wide range of climate. This, coupled with its prolificacy under favorable conditions, places this species foremost among grasshopper pests. The migratory habits of both adults and young make any local outbreak a serious menace to the whole countryside. Owing to the fact that this species is a general feeder, very few, if any, crops are immune. These considerations make international cooperative control measures on the part of the individuals of the community of utmost importance.

One of the main points brought out in this study is the important role that temperature plays in the development of this insect. The time of hatching in the spring and the subsequent seasonal development are based on this factor. From year to year the abundance of this grasshopper can be more or less reliably forecast if a careful record of weather conditions during egg-laying and hatching periods has been kept. Early spring hatches, caused by unusually high temperatures before May 1, when followed, as is often the case, by periods of cold, inclement weather, are unfavorable to the pest. The period of the first instar is the critical time, as the grasshopper in its subsequent instars is more hardy. Delayed hatchings, due to late springs, often cause late damage by grasshoppers in sections where least expected. This was the case in eastern Montana during the summer of 1927. Here it was believed that there would be no damage from grasshoppers that summer, as few or none were to be seen during June. Little or no attention was therefore paid to the situation. The season, however, was late, and the eggs did not hatch until a month or so after the usual time. The farmers were not aware of the fact that a rather serious outbreak was in progress until considerable damage had been done. Hour also was that, since no grasshoppers had hatched by June 1, there would be no damage. It cost one farmer 60 acres of good sweet-alfalfa because he was not aware of the situation and did not maintain the usual vigilance. A knowledge of what to expect and where to look is more than half the battle in grasshopper control. The necessary advance information can be obtained through careful surveys to determine the abundance and location of the eggs in the fall, close attention being paid to the weather conditions during the periods of egg laying and hatching. With this information at hand, early, concerted, destructive action produces the best results.

A knowledge of the numerous enemies of this insect increases one's faith in the ability of nature to establish an equilibrium in the scheme of life so often upset by the doings of mankind. It also shows the necessity for preserving our bird life, for every grass hop-

for the protection and preservation of game birds in grasshopper districts, and for the inclusion of poultry raising as a part of the program in diversified farming.

CONTROL MEASURES

Much has been written on grasshopper control, and most of this is a repetition of previous recommendations as to cultural methods and the use of poisoned-bran mash as a bait. The only thing that need be stressed here is the necessity for the exercise of a little more foresight than hindsight on the part of the farmer in applying control measures. A better knowledge of the vulnerable points in the life history and habits of this insect should help to this end. From the standpoint of economy and efficiency this pest should be combated during the egg or earlier nymphal stages.

Fall or spring plowing of egg-infested fence rows and stubble land and the ground around old straw stacks is practically 100 per cent efficient. A 40-acre field of rye in Hill County, Mont., was totally destroyed by adults of *M. atlanis* in August, 1926, and was heavily infested with eggs that year. Acting upon the advice of the county agricultural agent, the owner plowed and disked this field late in the fall. The next spring only a very few nymphs were hatched in this piece of ground. Another field, of wheat stubble, was heavily infested with eggs of *atlanis* in that same year, the number of egg pods running as high as 18 around the base of one wheat stub. This field was plowed and thoroughly worked early in the spring of 1926, before the eggs hatched, and was planted to corn. Here, too, only a few hatched out, and these starved to death before the corn came up. Newly hatched nymphs must feed immediately and soon starve if none is within easy reach. Good summer-fallow of grasshopper-infested land in stubble, or grasshopper-infested land grown up to Russian thistles, greatly reduces the grasshopper hazard.

Plowing as a control measure need not stop when the eggs have hatched. It can sometimes be used against the nymphs in connection with poisoning operations. The nymphs can be segregated in a very small area by commencing to plow on the outside of an infested field and working toward the center. This continually forces the nymphs toward the middle of the field, where a maximum kill by poisoning can be obtained with a minimum expenditure of labor and material. A strip of plowed ground 50 to 100 feet wide acts as a barrier against nymphs moving in from adjacent breeding grounds.

The migrating habits of the nymphs make any breeding ground a menace to all neighboring cultivated fields. A careful watch of these heavily infested areas should be kept, because sooner or later, usually after the second instar, the nymphs start moving into the cultivated crops. Effective barriers should then be placed across the line of migration. This can often be done by the use of the poisoned-bran mash or, as in one instance in northern Montana, by the use of a spray of 1-to-64 solution of sodium arsenite or of sodium-arsenite dust. A study of the feeding curve indicates that to insure the best results the poisoned-bran mash should be scattered

before 9 a. m. Very good results have been obtained on dry migrated lands in Montana by the use of a mixture of bran, grease, and water in the usual proportions. The preference of the insect for succulent food is no doubt the explanation.

It is much more difficult to combat grasshoppers when they are in the adult stage than while they are nymphs and, if it is at all possible, they should be prevented from reaching this stage. The adult grasshoppers may not only damage crops in one locality but may fly to other fields miles away. A period of from 30 to 50 days is usually required for their nymphal development, and this period should afford ample opportunity to combat them.

SUMMARY

The lesser migratory grasshopper, *Melanoplus atlanis* Riley, is indigenous to the North American Continent, having a greater geographical range than any other species of its genus. It is found in practically all parts of the United States, from the Atlantic to the Pacific and from sea level to altitudes of 9,000 to 11,000 feet. It occurs over practically all but the tropical lowlands of Mexico, and extends north into Canada.

Its habitat in general is in localities having light, sandy soil. In the Northwest, wheat-stubble fields containing thick growths of Russian thistle form ideal breeding grounds for this insect.

As an insect pest, its greatest damage has been done west of the Mississippi River, and especially in the northern, hard spring wheat area, including the Provinces of Canada from Manitoba westward. Of all the species of grasshoppers in the United States, this one is probably of greatest economic importance.

It is one of the most variable of the Melanopli. Specimens from identical localities show considerable individual variation in size and coloration.

The egg of this insect is whitish yellow or cream colored and is between 4 and 5 millimeters long. The number of eggs to a pod ranges from 8 to 20. The eggs are usually found in light, sandy soil, along fence rows protected by Russian thistles, around the lane of wheat stubble or alfalfa, and seldom in adobe or heavy soil. In northern Montana the eggs are laid during the latter part of August and on into the fall. These eggs usually show an advanced degree of embryological development before winter sets in. In the spring only a few days of hatching temperatures are necessary to cause them to hatch. Minimum hatching temperatures are between 60° and 62° F., and the optimum from 80° to 85°. The hatching period may extend over a month or even six weeks, and may be expected to begin at any time from April 15 to June 15, when the soil temperatures range above 70° for from 6 to 20 hours each day over a period of a week or 10 days.

Melanoplus atlanis passes through five, and sometimes six, instars in its nymphal development, five being the normal number. The extra instar occurs between the regular third and fourth instars. The length of the nymphal development depends upon weather conditions, and may extend over a period of from 30 to 50 days.

Copulation first takes place about two weeks after the adult stage is reached; then follows a period of two to three weeks, more or less,

before the first egg is laid; during this time the males and females are often in coition. After the female has deposited her first egg pod she may again be seen in coition with a male. In laboratory experiments the greatest number of eggs laid by a single female was 197.

At some time during the nymphal stage a migration usually takes place from the breeding grounds toward more cultivated land. This nymphal migration, so far as it has been observed, usually occurs during the third, fourth, and fifth instars. It commences sometime in the morning when the air temperature is about 75° F., and ceases at about 4 p. m. The minimum temperature of the air for the migration of nymphs is about 68° F. at the height of 5 feet above the ground.

Migration of the adult on the wing occurs only in years when this species is abundant. This grasshopper is a very strong flier and migrates in large swarms over great distances. These migrations usually occur in the latter part of July and in the months of August and September. There has been no satisfactory explanation regarding their causes.

This species is almost omnivorous in its food habits and shows a preference for succulent plants. The optimum feeding time is from 8 to 11 a. m., when the sky is clear, when there is little or no wind, and when the air temperature ranges from 70° to 80° F.

The enemies of this grasshopper are numerous. Domesticated fowl, gophers, wasps (Sphecidae), and robber flies (Asilidae) are predatory upon the nymphs and adults. The larvae of blister beetles (Meloidae), bee flies (Bombyliidae), and ground beetles (Carabidae) are predatory upon the eggs. One of the greatest enemies is a flesh fly (family Sarcophagidae) which lays living maggots on the grasshopper.

One point emphasized in the present study is the importance of temperature in the occurrence of this insect. Weather conditions regulate the seasonal history and abundance.

An effective control measure is the poisoned bran mash, used during the nymphal stage and applied in order that the grasshoppers may get the poison during the optimum feeding time. Control measures must be based on a study of the life history, habits, and ecology of this insect.

LITERATURE CITED

(1) BLATCHLEY, W. S.
1920. ORTHOPTERA OF NORTHEASTERN AMERICA WITH SPECIAL REFERENCE TO THE FAUNAS OF INDIANA AND FLORIDA. 784 p., illus. Indianapolis.

(2) CAUDELL, A. N.
1903. NOTES ON ORTHOPTERA FROM COLORADO AND NEW MEXICO, ARIZONA, AND OTHER LOCALITIES IN THE SOUTHWEST. U. S. Nat. Mus. Proc. 26: 775–809, illus.

(3) COOLEY, R. A.
1925. MONTANA INSECT PESTS FOR 1924 AND 1924, WITH THE BIENNIAL REPORT OF THE STATE ENTOMOLOGIST OF MONTANA. Mont. Agr. Expt. Sta. Bul. 170, 30 p., illus.

(4) FERNALD, C. H.
1888. THE ORTHOPTERA OF NEW ENGLAND. 61 p., illus. [Boston].

(5) HEBARD, M.
1917. NOTES ON MEXICAN MELANOPLI (ORTHOPTERA: ACRIDIDAE). Acad. Nat. Sci. Phila. Proc. 69: 251–275, illus.

(6) Hebard, M.
1925. The orthoptera of South Dakota. Acad. Nat. Sci. Phila. Proc. 77: 33–155, illus.
(7) Herrick, G. W., and Hadley, C. H., Jr.
1916. The lesser migratory locust. N. Y. Cornell Agr. Expt. Sta. Bul. 378, 45 p., illus.
(8) Hubbell, T. H.
1922. Notes on the orthoptera of North Dakota. Mich. Univ., Mus. Zool. Occas. Papers No. 113, 56 p.
(9) Morse, A. P.
1904. Researches on North American acridiidæ. 55 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 18.)
(10) ———
1907. Further researches on North American acridiidæ. 54 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 68.)
(11) Packard, A. S., Jr.
1883. The embryological development of the locust. U. S. Ent. Comm. Rpt. 3: 263–285, illus.
(12) Rehn, J. A. G.
1903. Notes on the orthoptera of New Mexico and western Texas. Acad. Nat. Sci. Phila. Proc. 54: 717–727.
(13) ———
1904. Notes on orthoptera from northern and central Mexico. Acad. Nat. Sci. Phila. Proc. 56: 513–549.
(14) ———
1904. Notes on orthoptera from Arizona, New Mexico, and Colorado. Acad. Nat. Sci. Phila. Proc. 56: 562–575.
(15) ———
1907. Notes on orthoptera from southern Arizona, with descriptions of new species. Acad. Nat. Sci. Phila. Proc. 59: 24–81, illus.
(16) ——— and Hebard, M.
1905. The orthoptera of Thomas County, Georgia, and Leon County, Florida. Acad. Nat. Sci. Phila. Proc. 56: 774–802.
(17) ——— and Hebard, M.
1906. A contribution to the knowledge of the orthoptera of Montana, Yellowstone Park, Utah, and Colorado. Acad. Nat. Sci. Phila. Proc. 58: 358–418, illus.
(18) ——— and Hebard, M.
1918. An orthopterological reconnoissance of the southwestern United States. Part I, Arizona. Acad. Nat. Sci. Phila. Proc. 69: 365–402, illus.
(19) ——— and Hebard, M.
1911. Preliminary studies of North Carolina orthoptera. Acad. Nat. Sci. Phila. Proc. 62: 615–650.
(20) ——— and Hebard, M.
1911. Orthoptera found about Aweme, Manitoba. Ent. News 22: 5–10.
(21) ——— and Hebard, M.
1916. Studies in the dermaptera and orthoptera of the coastal plain and piedmont region of the southeastern United States. Acad. Nat. Sci. Phila. Proc. 68: 87–314, illus.
(22) Riley, C. V.
1875. Seventh annual report on the noxious, beneficial, and other insects of the State of Missouri. Missouri State Ent. Ann. Rpt. 7, 196 p., illus.
(23) ———
1877. The locust plague in the United States. . . . 236 p., illus. Chicago.
(24) ——— Packard, A. S., Jr., and Thomas, C.
1878. First annual report of the United States entomological commission for the year 1877, relating to the Rocky Mountain locust and the best methods of preventing its injuries and of guarding against its invasions. 477 p., illus. Washington, D. C. [With 27 Appendices, 295 p., separately paged.]

(25) SAUSSURE, H. DE
1861. ORTHOPTERA NOVA AMERICANA (DIAGNOSES PRÆLIMINARES). Rev. et Magasin de Zool. (2) 13: 156–164.

(26) SCUDDER, S. H.
1880. LIST OF THE ORTHOPTERA COLLECTED BY DR. A. S. PACKARD IN THE WESTERN UNITED STATES IN THE SUMMER OF 1877. U. S. Ent. Comm. Rpt. (1878/79) 2, 322 p., illus. (Appendix II, p. [23]–[28], separately paged.)

(27) ———
1897. REVISION OF THE ORTHOPTERAN GROUP MELANOPOLI (ACRIDIIDAE), WITH SPECIAL REFERENCE TO NORTH AMERICAN FORMS. U. S. Natl. Mus. Proc. 20: 1–421, illus.

(28) ———
1898. THE ALPINE ORTHOPTERA OF NORTH AMERICA. Appalachia 8: 299–319, illus.

(29) THOMAS, C.
1873. SYNOPSIS OF THE ACRIDIDÆ OF NORTH AMERICA. U. S. Geol. Survey Ter., v. 5, 262 p., illus.

(30) WALKER, E. M.
1899. NOTES ON SOME ONTARIO ACRIDIIDÆ. PART III. Canad. Ent. 31: 29–36.

(31) ———
1902. A PRELIMINARY LIST OF ACRIDIIDÆ OF ONTARIO. Canad. Ent. 34: 251–258.

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